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Properties of Traditional Clay Roof Tiles Manufacture in Kelantan, Peninsular Malaysia

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ABSTRACT

The industry of traditional clay plain tiles, Singgora tiles, has been established in Kelantan for almost a century. However, the studies conducted in this field are insufficient. The purpose of this study is to test the properties of existing Singgora tiles to find out whether they satisfy the standard requirement. The tests of dimension measurement, surface quality, water absorption and flexural were done. The relative percentage constituent mineral and microstructure of Singgora tiles were measured by using XRD and SEM technique respectively. The physical test shows the length and thickness of Singgora tiles is not satisfied the standard. In addition, most of the samples have the defect on the surface and high water absorption. It is found that the strength of Singgora tiles is lower than the minimum requirement of standard. The presence of high percentage of quartz is observed in the mineral phase of Singgora tiles and the SEM analysis proved the incompletes vitrification among their microstructures.

Keywords: *Tile, Conservation, Roofing, Singgora, Malay House*

INTRODUCTION

A roof is an essential covering that is placed on top of the building. The basic purpose of roof is to provide protection for the structure, fabric, occupant and content of the building (Harvey, 1972). According to Abdul & Wan (2002), in selecting the materials for building, high priority should be given to the strength of material. Therefore, the strength of roof is vitally important and a faulty of roof such as leakage will allow the penetration of rainwater into the building thus becomes a source of problem to other structures (Feilden, 2003).

A Singgora tile (Figure 1) is a roof covering for old building which commonly found predominantly in Kelantan and Terengganu. It is become highly important as a roofing material of conservation for repairing, replacing or even reconstructing them totally. It can last for up to 150 years and used traditionally in dwellings, palaces and community centers (Hanafi, 1996). Singgora tiles is the most distinctive and decorative historic roofing materials because of their great features in shape and colour. The colour is pale orange which imparts the natural hue to the building. In terms of aesthetic value, Singgora tiles form a unique look, like fish scales, when arranged in the roof framework (Killmann et al., 1994). Singgora tile has formed a symbol of identity to the Malaysian traditional architecture. One of the famous buildings that used Singgora tiles is Jahar Palace in Kelantan which built in 1887 (Nasir, 1979).

Figure 1: Singgora Tiles

The history of the manufacture of Singgora tiles in this country is obscure because there is no proper record of their existence. However, many scholars believed the industry is originated from the south of Thailand (Adit, 1994; Salinger, 1997) which was a part of the Malay Kingdom in the past. The similarity found in the roofs of buildings in East Coast of Malaysia and Southern Thailand show a strong trade links and good relationship between them in the past. Singgora tiles become an important component in the history of Malaysia which presents the influence of Thailand architecture to the building in Kelantan and Terengganu.

Singgora tiles are produced using clay that is moulded and then burnt in a kiln. This handmade tile is manufactured in such a way that their surface is more textured, the size is less uniform but perhaps more attractive colour. Singgora tiles are sustainable product which has the thermal mass characteristic to help the building react to temperature variations throughout the day. During peak temperature, Singgora tiles will absorb the heat, rather than transfer it to the living space. This keeps the interior of the home comfortable during peak temperature hours. At night, the absorbed heat is released, keeping the home to stay warm. Nevertheless, Singgora tiles help to improve building comfort and reduce the demands for peak energy. In addition, the Singgora tiles are installed to allow greater airflow between the tile and the roof batten. Thus, the insulating properties of the roof are improved.

Nowadays, most of the demand for Singgora tiles is to repair the damage of roofs in old buildings. The decline of this material today is affected by changing housing style. Singgora tiles failed to cope with the present housing style make them started to seem obsolete, old-fashioned and impractical. Besides, the emergent of modern material and the inferior quality of the product itself have drive down their market. Nevertheless, the decreased in consumer demand becomes the factor to the decline of Singgora tiles industry. Unlike other craft industries, such as Sayong pottery in Perak, this industry is at risk as there is only one factory which has survived until today.

Little attention has been given to the studies on Singgora tiles attributed to the limited information on this industry. In year 1991, Ministry of Housing and Local Government in Malaysia at that time has listed Singgora tiles as one of the neglected traditional building material (USM, 1991). The history of Singgora tiles is described by Adit (1994) and Salinger (1997). The production of Singgora tiles is well documented (Hanafi, 1996) and little has been published on the improvements that can be made to the product's quality (Shamsu, 2013; Zulkarnian & Siti Norlizaiha, 2013). This paper is intended to assess the standard of the Singgora tiles which is available in the market at present. The results of this study may be useful to point the way for further research in improving the production of Singgora tiles.

METHODOLOGY

The samples were collected from the regular production of Singgora tiles located at Bachok, Kelantan. Sample and data collection were done based on these area because they are the sole supplier of Singgora tiles in Malaysia. In order to check whether the existing roof tiles are up to the standards, mainly four tests were done including dimension check, surface quality, water absorption and flexural strength. In addition, the XRD and SEM analysis were also conducted to determine the mineral and textural property of Singgora tiles.

Dimension Measurement

The vernier caliper and micrometer were used to measure the length, width and thickness of Singgora tiles, to the nearest 0.2mm. The test was conducted according to BS EN ISO 10545-2: 1997 (Section 2). The samples were measured according to the dimension line as shown in the Figure 2. For each sample, the average dimension of the width, length and samples was the average of four measurements. For thickness measurement, four lines was draw across the uneven surface of Singgora tiles at a distance of 0.125, 0.375, 0.625 and 0.875 times the length of the samples (measured from the end). Based on those lines, the thickness was measured at the thickest point on each line.

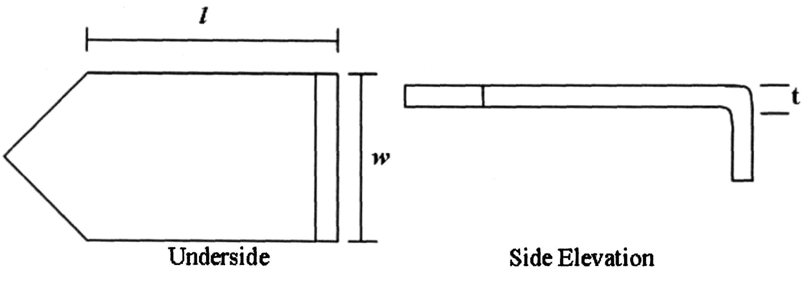


Figure 2: The Dimension Line of a Selected Sample

Surface Quality

The surface quality of fired Singgora tiles was observed with the naked eyes at a distance of 30cm to 40cm, under normal lighting as described by BS EN 1304 (2005). In addition, the surface was also observed using microscope Olympus SZX7 to get a better view of defect. The defects found were classified according to the terminology of defect in BS EN 1304:2005 and BS EN 14411:2006. The defect was measured using vernier caliper to the nearest 0.2mm.

Water Absorption

The method used to determine the water absorption was according to BS EN ISO 10545-3: 1997. The laboratory equipments used were digital balance (capacity of 4200g and sensitive to 0.01g), heater, distilled water, iron wire, thermometer and damp cloth. Five pieces of specimen were tested. The samples were brought to a constant weight by drying with oven Carbolite PF 30. The samples were dried at temperature 110±5°C for 24 hours till constant mass was reached, which the different between two successive weighed at two hours interval showed an increment of loss less than 0.2% of the last previously determined weight of specimen.

The percentage of water absorption of Singgora tiles was determined by placed the tile in distilled water. The samples were completely immersed and do not touch the bottom and others sample. The container was heated with a heater and soaked for four hours at boiling point. After that, the samples were left cooling for four hours immersed in water. Once the tiles were removed from the beaker, excess water in the surface was removed using damp cloth. The percentage of water absorption is expressed in the formula;

$$Percentage\ of\ water\ absorption = \frac{W_2-W_1}{W_1}\ x\ 100 \quad \text{.....................(1)}$$

Where W_1=the mass of dry tile; W_2=the mass of wet tile

Flexural Strength

The strength test was carried out according to ASTM C1167-03 (Section 6.3). Five specimens of Singgora tiles were tested. Each piece was cut to a dimension of 110mm length and 70mm width to fix the length of cylindrical rod of Instron 4469 machine. The selected span size was 75mm, based on the nominal gauge between the batten when installed at frameworks of roof as stated by Hanafi (1996). The specimens were prepared using dry method test. They were dried at temperature 110±5°C for 24 hours till constant mass reached where the different between two successive weighing at two hours interval showed an increment of loss not greater than 0.2% of the last previously determined weight of specimen. The samples were tested not later than 2 hours reached the room temperature. The equation used to calculate the modulus of rupture is;

$$Flexural\ Strength = \frac{3FL}{2bh^2} \qquad (2)$$

Where F=breaking load (N); L=span between two rods support (mm); b=width of specimens (mm); h=minimum thickness of the test specimens, measured after the test, along the broken edge.

The accepted results were only considered the samples that break within the central position of length equivalent to the diameter of the central rod. The break sample that has a dark area, steely appearance and sharply delineated from the surrounding normal colour (also known as black heart or black core) was accepted.

Mineralogical and Textural Analysis

A mineralogical analysis of fired samples was carried out by using X-ray diffraction analysis. The machine used was X-Ray Diffractometer D5000. The Scanning Electron Microscopy (SEM) analysis was used to study the textural property of the Singgora tiles by using Scanning Electron Microscope FEI Quanta 200F. The samples, which have a good quality of surface, were cut to a dimension of 1cm length and 1cm width.

RESULTS AND DISCUSSION

Dimension Measurement

Figure 3 to 5 shows the deviation of length, width, and thickness of Singgora tiles from the mean value. There is no work size of length specified by the manufacturer. Therefore, the average dimension of ten samples, which is a total of 40 measurements, is considered as work size in the experiment.

According to the BS EN 14411:2006 (Annex F), the deviation of length and width of tiles shall fall within ±2.0% of the work size while the thickness is within ±10.0%. The work size of length, width and thickness of Singgora tiles are 208.32mm, 163.78mm and 6.75mm respectively. Only 20% of the length and 10 % of thickness are meeting the standard requirement. Overall, although the width of all samples is within the allowable deviation, the samples are considered did not satisfy the standard. The reason of failure is their length and thickness is not fulfilling the minimum requirement of deviation. The variation in the dimensions of green tiles is contributed by the variation size of mould to shape the tiles. In fact, good tiles should be consistent in size and only vary within allowable tolerance to avoid the different joint sizes and to ensure the proper installation and smooth flow of water.

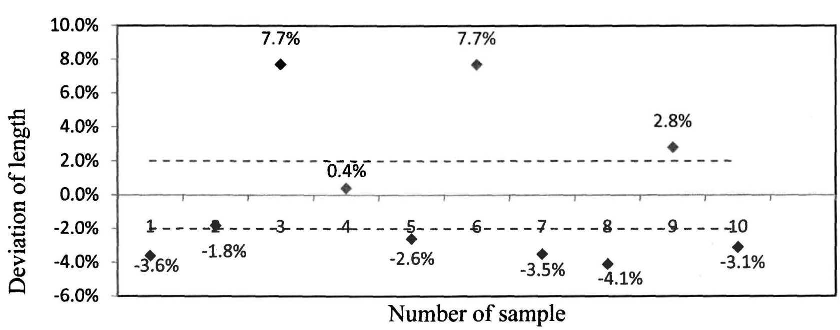


Figure 3: The Deviation of Length from the Average Value

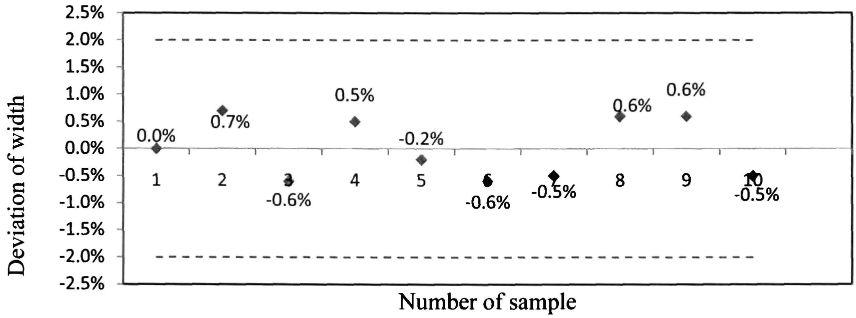


Figure 4: The deviation of width from the average value

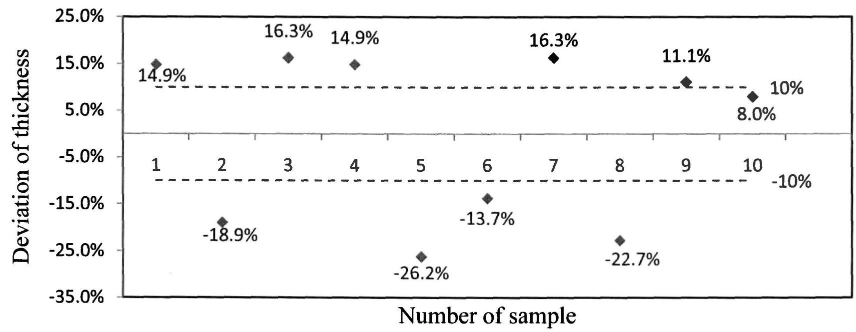


Figure 5: The Deviation of Thickness from the Average Value

Surface Quality

According to EN 14411:2006, 95% of the ceramic tile surface shall be free from visible defects that would impair the appearance of a major area of tiles. On the other hand, ASTM C1167-03 (Sec. 5.2) describes that the tile that has good quality shall be free of defects, deficiencies or bloating, because it would interfere the proper laying of tiles. The surface quality of Singgora tiles are depends on the surface defect. The surface failure of Singgora tiles are described in the Table 1.

Table 1: Surface Quality of Singgora Tiles

Surface fault	No. of Sample									
	1*	2*	3	4	5	6	7	8	9*	10
Crack *(BS EN 1304:2005)*	√		√							
Pit *(BS EN 1304:2005)*			√						√	
Chip *(BS EN 1304:2005)*		√								
Unevenness *(BS EN 14411:2006)*						√				
Rough Edge *(BS EN 14411:2006)*	√	√		√	√	√	√	√	√	√
Impurities					√					
% of visible defect	6	6	4	2	4	4	2	2	7	2

* Does not satisfy BS EN 1411:2006 requirement

Thirty percent of the samples did not fulfill the requirement of BS EN 1411:2006 because the defect on their surface is more than 5%. Most of the defect that occurs on the product is rough edge or an unintentional irregularity along the edge of a tile. The common part of tiles that has this type of defect is along the edge of hook. Besides, 20% of the samples have crack and pit. The crack is not running throughout the entire thickness of the product while pit is a fraction of material detached from the body of the product on the visible surface of the product with a mean dimension of over 7mm. In addition, 10% of the samples have the defect of chip, impurities and unintentional depression in the surface of a tile or also known as unevenness.

Figure 6 presents the view of defect under the microscope. Figure 6 (a) shows the presents of tiny pit and hairline crack in the surface of Singgora tiles. Besides that, the pore and impurities are also observed as shown in the Figure 6 (b) and 6 (c) respectively. This defects that occur on the product might be contributed by the fault of equipment or human during production.

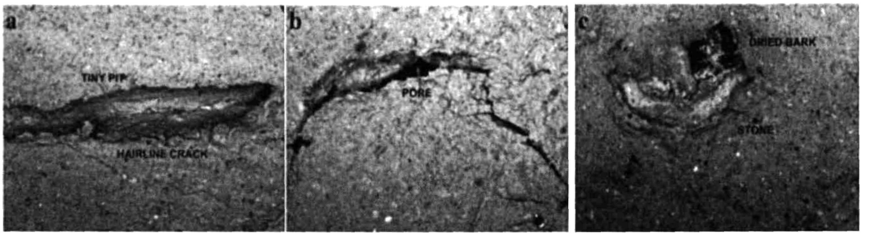


Figure 6: The Defect on the Surface of Singgora Tiles (0.8x magnifications)

Water Absorption

The percentage of water absorption of Singgora tiles is recorded as 22.0%. Singgora tiles are categorized into the Group III, where the water absorption is greater than 10% as prescribed in BS EN 14411 (2006). Under this category, this ceramic tile is considered to have high water absorption with porous body.

According to Dan et al. (2009), the pore dimension and distribution is influenced by the quality of raw clay, the amount of water, the presence of additives or impurities in the raw clay, and the firing temperature. He adds the percentage of water absorption will determine the capacity of the fluid to be stored and circulated within the product, which lead to deterioration and decrease the mechanical strength. The higher water absorption of clay product will trap more water which promoting the growth of moss and ficus.

Flexural Strength

Figure 7 displays the bending strength of Singgora tiles. The average strength of Singgors tiles is 4.90 N/mm^2. It is worth mentioning that this value is less than the minimum typical strength of roof tile, 8.00N/mm^2, as described by ASM (Kuhn et al., 2000) and BS EN 14411 (2006). The experimental data for each sample is unevenly distributed. The regular production of Singgora tiles has a high value of standard deviation which is ±1.26 N/mm^2. Therefore, the Singgora tile is considered as unreliable product.

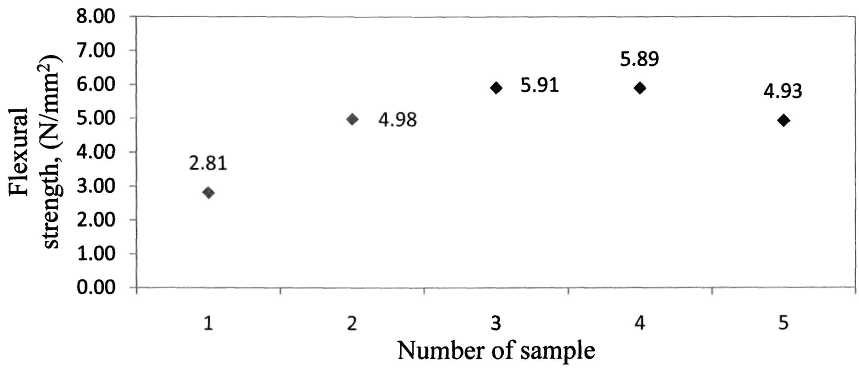


Figure 7: The Flexural Strength of Singgora Tiles

Sidjanin et al. (2007) notes that the mechanical properties of roofing tiles are influenced by their microstructure; which vary based on the mineral composition of clay and the firing temperature. In term of mineral composition, the variation of compressive strength is due to the difference in the mineralogy properties of clay (Manoharan et al., 2011). Through firing, the compressive strength is improved by decreasing the porosity and reducing the formation of crack in the fired clay (Monteiro & Vieira, 2004). It is not surprising the value of flexural strength of Singgora tiles is low since their percentage of water absorption is high.

The variation of strength among the samples of Singgora tiles is contributed by technique to fire the product. The kiln used in the small scale industry of Singgora tiles is inefficient and consuming large fuel quantities. It has produces a varied quality of product which depends on the location of the tiles in the kiln. The tiles that fired near to the source of fire is burnt hard whereas those fired at the top is burnt soft.

The high standard deviation among the sample is also contributed by the presents of impurities inside the fired body. After the test was conducted, it was observed that there was a tiny pit and black heart along the broken edge of samples (Figure 8). Black heart is generally owing to the reduction of iron minerals during the firing process (ASTM C1167-03). The pin hole, or pore, is formed when the organic impurities is burned out. The burnt impurities during firing have left the pore inside the body of tiles. The pore is correlated well with the strength of the product because high porosity will contribute to the low strength of ceramic (Van Vlack, 1964).

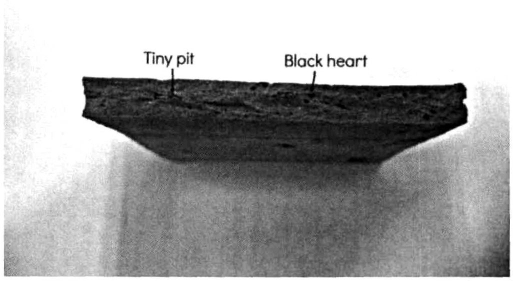


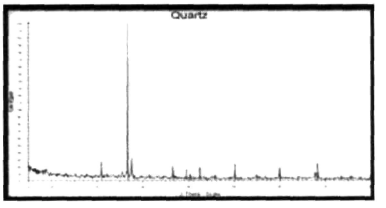
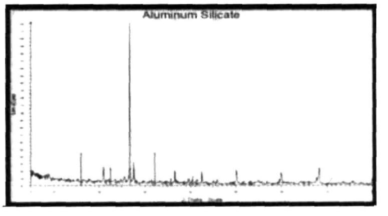
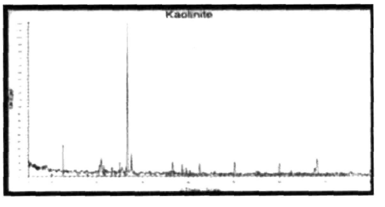
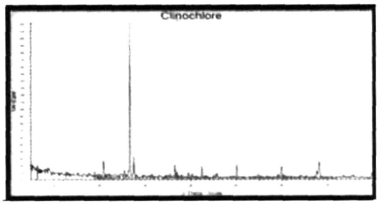
Figure 8: Broken Edge of Singgora Tiles

Mineralogical Properties

Table 2 displays the percentage of kaolinite, illite, quartz and chlorite in Singgora tiles. The XRD results show that the quartz is the most common mineral phases of Singgora tiles. Besides, the Singgora tiles also consist of illite and kaolinite, with minor amounts of chlorite.

According to Brown and Gallagher, (2003), in the deposit of clay, there are several elements presence in the clay including the accessory mineral, impurities and the most important is clay mineral, which constitute less than 35% clay deposit and categorised by similarity in crystal structure. They add the type and amount of these elements will determine the composition and property of clay. Ash et al. (1982) notes the essential clay mineral for brick and tile making are; kaolinite because of their good sintering, illite which can produce plasticity, and quartz which act as stabiliser.

Table 2: Mineral Composition of Singgora Tiles

Mineral Phase	Reflection	Peak (Å)	Wt. %	XRD Pattern
Quartz	011	26.640	71.97	
Illite	110	15.841 & 32.066	18.90	
Kaolinite	001	12.402	18.76	
Chlorite	002	6.247	8.10	

Textural Evolution

Figure 9 shows the textural surface of the Singgora tiles. The image of surface is taken at 3000x magnification which according to Elssner et al., (1999), this magnification will make the scanning electron monograph possible to easily recognise and determine grain size, shape and distribution. The image shows the microstructure of a porous body and the vitrification of the ceramic particles was incompletes. It makes the tiles being more porous and easily absorbs the moisture. This SEM result is consistent with the high water absorption of Singgora tiles.

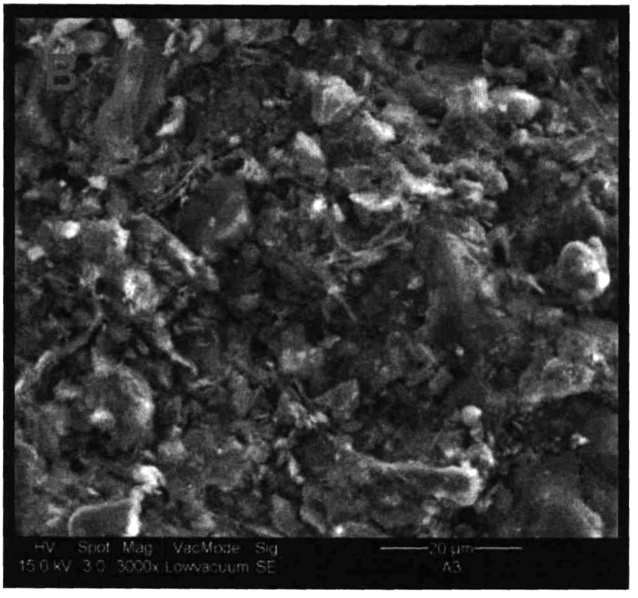


Figure 9: The Surface of Singgora Tiles

A successful firing of clay body is achieved when their strength and degree of vitrification is develop without deforming (Fraser, 2000). According to Cultrone et al., (2004), the vitrification of clay product can be clearly detected when the samples are fired at temperature between 900 and 1000°C. Bernasconi et al., (2011) notes that firing duration is the key parameter to promote the vitrification, which increasing in firing time will decrease the water absorption. As mentioned earlier, the traditional kiln is used to fire the Singgora tiles in the factory. The used of this primitive kiln may not achieve the temperature 900°C or the shorter firing time has lead to the failure of the product to achieve vitrification.

CONCLUSION

The properties of Singgora tiles existing in Kelantan are less than the standard requirement for clay roof tiles in terms of dimension, surface quality, water absorption and flexural strength. Study found that size of Singgora tiles is non-uniform where the variation of length and thickness is high. In term of the quality of surface, a lot of defects are found especially unintentional irregularity along the edge of a tile. Singgora tiles also have high water absorption and porous body. Furthermore, the flexural strength of Singgora tiles did not satisfy the minimum requirement of typical strength of roofing tiles. The abundance of quartz is observed in mineral phase of Singgora tiles. The textural analysis has proved the high water absorption of the product where the microstructure of the tiles body is porous and the vitrification of particles is incomplete. Further research to improve the quality of Singgora tiles is necessary because this material is important for the conservation and maintenance work, and newly construction of traditional building.

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